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Offshore Surface Surveillance with HF Radar

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13. ABSTRACT (*Maximum 200 words*)

HF groundwave radars are routinely deployed for ocean roughness and current monitoring. These low-powered radars see ship traffic as annoyance echoes, and they employ filtering techniques to remove ship and boat echoes. A simple processor addition to such radars could provide surface target tracks out to the tens of miles distances. Neptune in the UK and the Moscow Insititute of Long-Wave Radiowave Communications offer radars for harbor management and monitoring coastal traffic. In this report, the performance of HF groundwave radar for surface targets is predicted for over the sea paths. The radar antenna location is taken to be at the shoreline and well coupled to a sea with typical ocean salinity. The radar parameters selected are easily achieved. The nominal 10 MHz operating frequency is a compromise between large antenna size required by low frequency operation and higher path losses experienced at higher frequencies. A transmitter average power of 1 kW (30 dBw) and a transmitter-receiver antenna gain product of 30 dBi are selected; these values are somewhat less than were suggested in a sales brochure. A 1 square-meter target yields a 20 dB signal to noise ratio (SNR) at 40 nmi. At slow speeds, the target can be obscured by the sea echo (dependent upon the spatial resolution cell size); this emphasizes that for small targets, resolution cell size is more important than energy density. Under relatively calm conditions, the target would be detectable at all speeds except zero, where the target might be obscured by land returns from antenna side lobes.

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OFFSHORE SURFACE SURVEILLANCE WITH HF RADAR

J. M. Headrick

Introduction and Summary: HF groundwave radars are routinely deployed for ocean roughness and current measurement, and these radars see ship traffic as annoyance echoes. Neptune in the UK and the Moscow Institute of Long-Wave Radiowavecommunications offer radars for harbor management and monitoring coastal traffic. In this report the performance of HF groundwave radar for surface targets is predicted for over the sea paths. The radar antenna location is taken to be at the shoreline and well coupled to a sea with typical ocean salinity. The radar parameters selected are easily achieved. The nominal 10 MHz operating frequency is a compromise between large antenna size required by low frequency operation and higher path losses experienced at higher frequencies. A transmitter average power of 1 kw (30 dBw) and a transmitter-receiver antenna gain product of 30 dBi are selected; these are somewhat less than the reference (1) brochure suggests. A one square meter target yields a 20 dB signal to noise ratio (SNR) at 40 nmi. At slow speeds the target can be obscured by the sea echo (dependent upon the spatial resolution cell size); this emphasizes that for small targets resolution cell size is more important than energy density. Under relatively calm conditions the target would be detectable at all speeds except zero where the target might be obscured by land returns from antenna side lobes.

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Radar Cross Section (RCS): Typical ship RCS run between 10 and 50 dBsm at HF. Figure 1 gives the RCS of a metallic monopole and a hemisphere (2). These canonical shapes can be used to estimate RCS at HF. From Figure 1 we can determine that a 4 m radius hemisphere has a maximum RCS of 16 dBsm at 12 MHz where it is resonant and can drop to minimum values as low as 6 dBsm at higher frequencies. Zero dBsm (1 square meter) is used for our predictions; this is a very small target, however results can be directly scaled for other target sizes. Reference (3) gives the results of measuring the RCS of small fishing craft and pleasure boats, and all are larger than 0 dBsm at mid HF Band operating frequencies

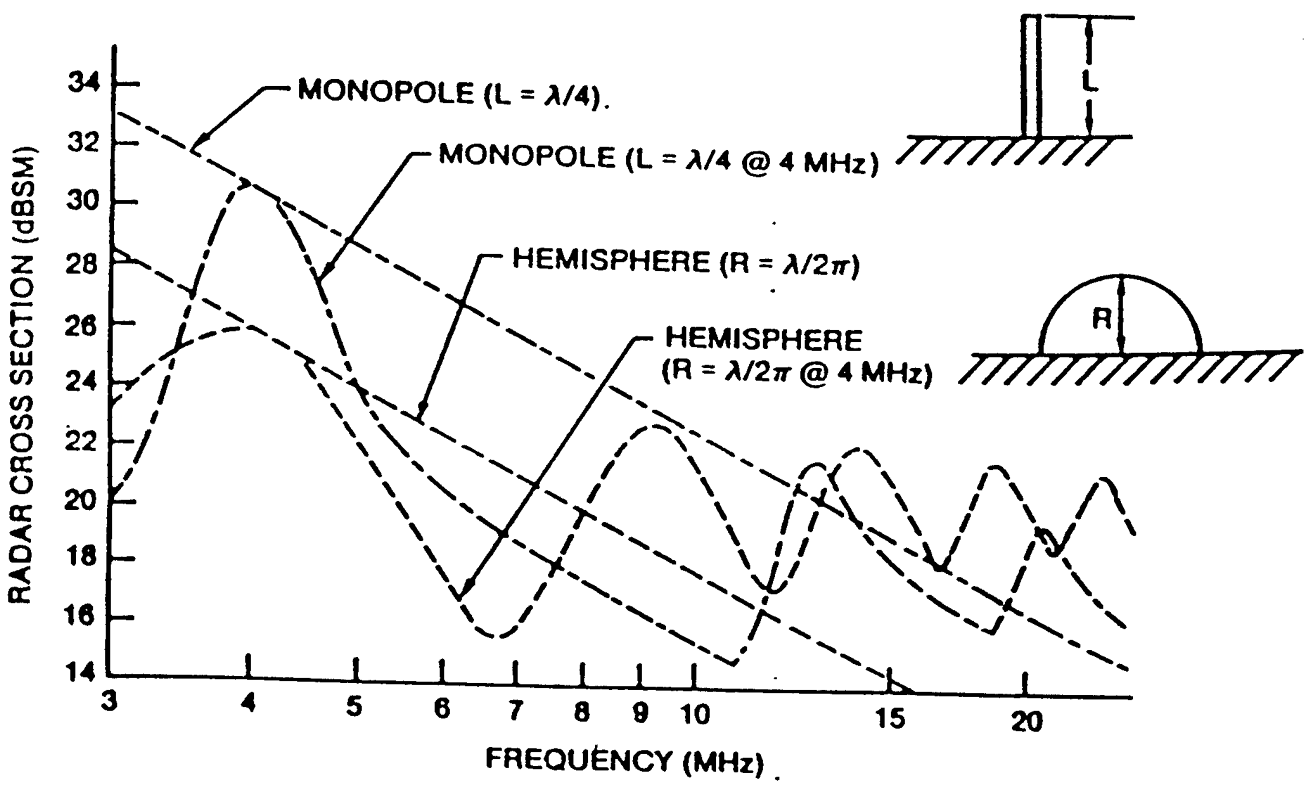


Figure 1 The vertical-polarization RCS of a hemisphere and a monopole on a perfectly conducting plane are plotted against radar operating frequency. The straight lines give maximum [first resonance] RCS.

Radar Equation: Figure 2 gives the radar equation and path loss curves parametric in operating frequency. Path loss is for a smooth sea and radar antennas and target at the surface (2). If the sea has been roughened by wind there can be additional loss.

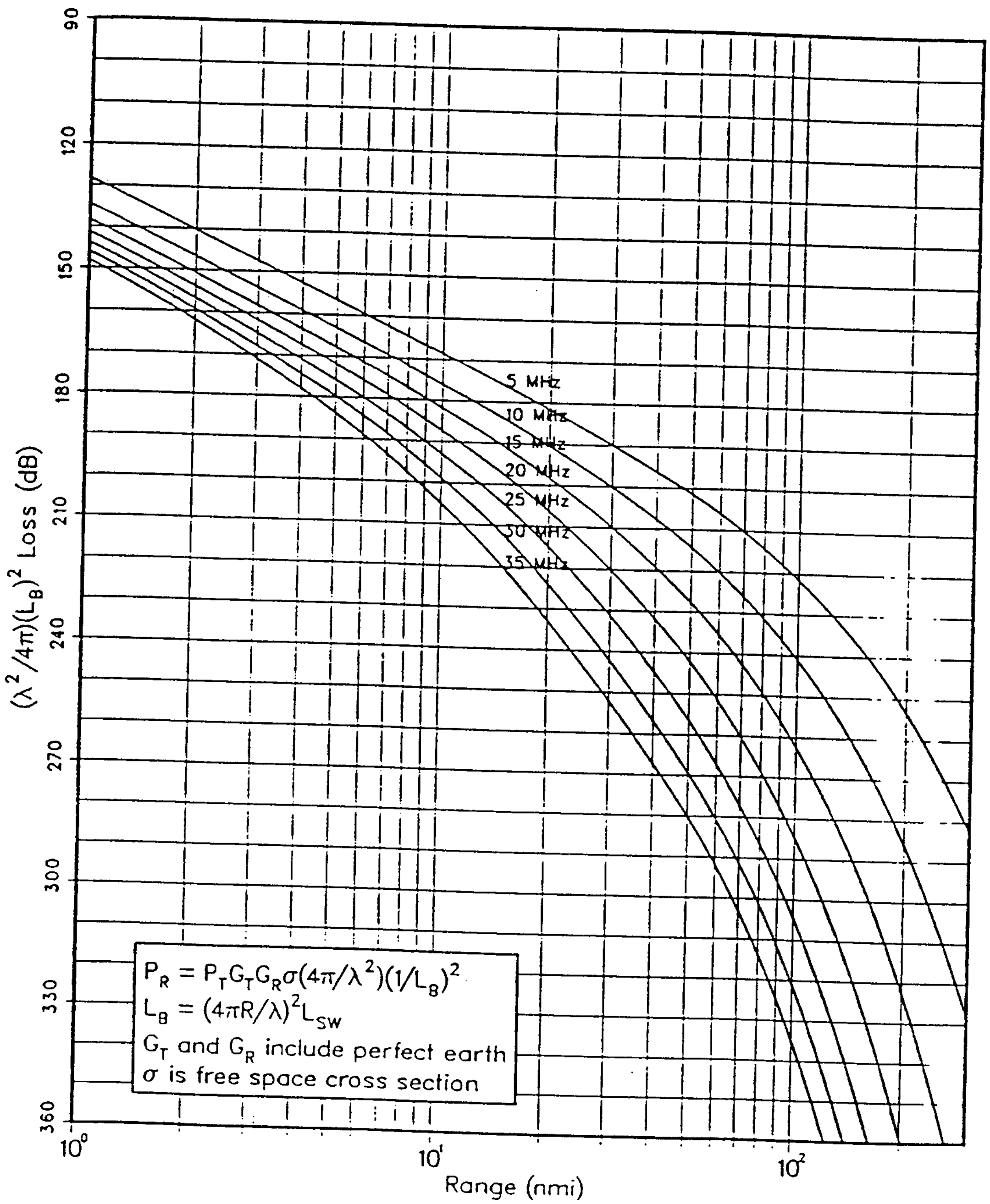
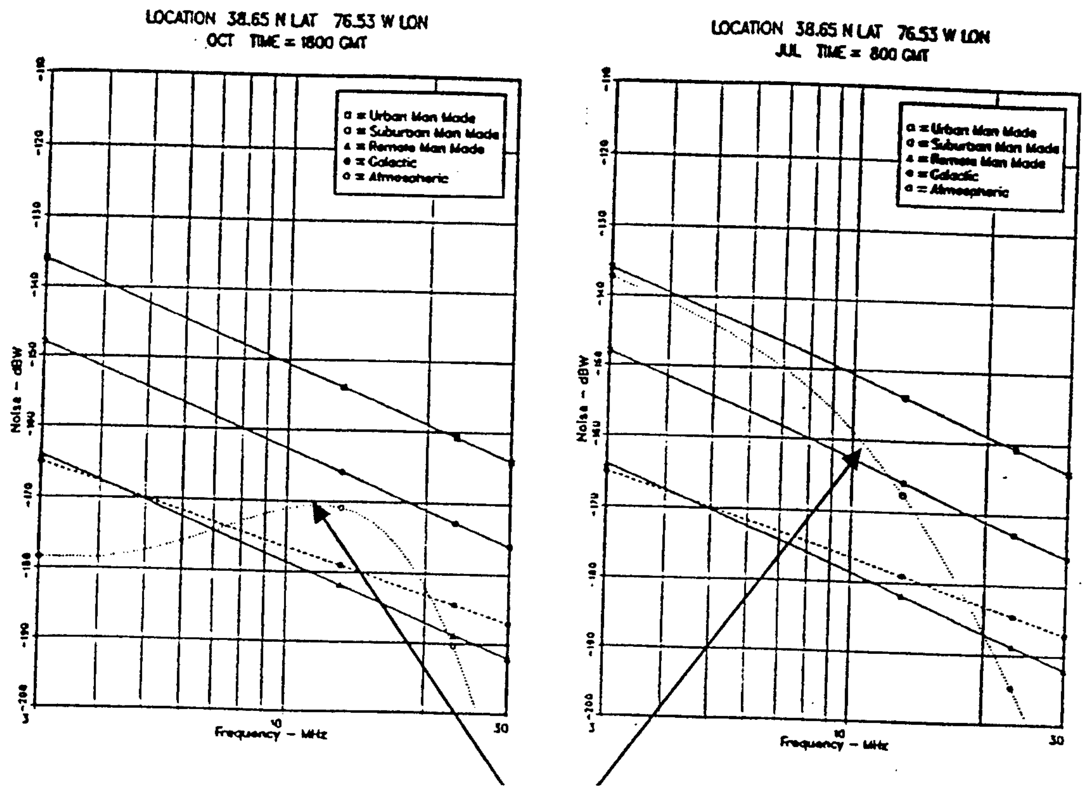


Figure 2 Curves for estimating groundwave radar performance are given as a function of range and are parametric in frequency. The polarization is vertical, the surface is smooth, radar antennas and the target are on the surface, conductivity is 5 S/m, and dielectric constant is 80.

Noise: HF radars are typically external noise limited where the sources are long range thunderstorm activity, galactic radiation, and man made interference. Natural noise is variable in time and location. Figure 3 is plotted from CCIR 322 [4] where (b) is for the highest atmospheric noise season at a mid-Atlantic east coast location. If operation at 10 MHz is considered, -158 dBw per Hz is the maximum atmospheric noise level. Since radar sites are generally selected to minimize man-made noise, for all days and seasons other than summer nights the noise levels will be lower.



(a) Note difference (b)

Figure 3 Noise power per hertz is given for (a) fall day, a relatively quiet time, and (b) summer night the time for highest atmospheric noise at 10 MHz.

Clutter: Surface targets are separated from the sea echo by Doppler discrimination. Figure 4 gives an example of a 30 dBsm, 13 knot target in the presence of sea clutter at operating frequencies of 5.90, 9.93, and 13.73 MHz. For this example the sea was roughened by a twenty knot wind but was not fully developed. This example was taken from data collected with an experimental radar with power and antenna gains similar to those used here, and the receive antenna aperture was about 250 m.(5) On the 9.93 MHz curve a line is drawn for the 0 dBsm and the 10 dBsm target level. The 10 dBsm target stands above the clutter except very narrow speed spans that coincide with the resonant lines, and modest shifts in operating frequency will uncover these blind speeds. A 0 dBsm target would be clutter obscured from approximately -7 to + 15 knots. The clutter covered target could have been exposed by increasing the receive antenna aperture by a factor of ten.

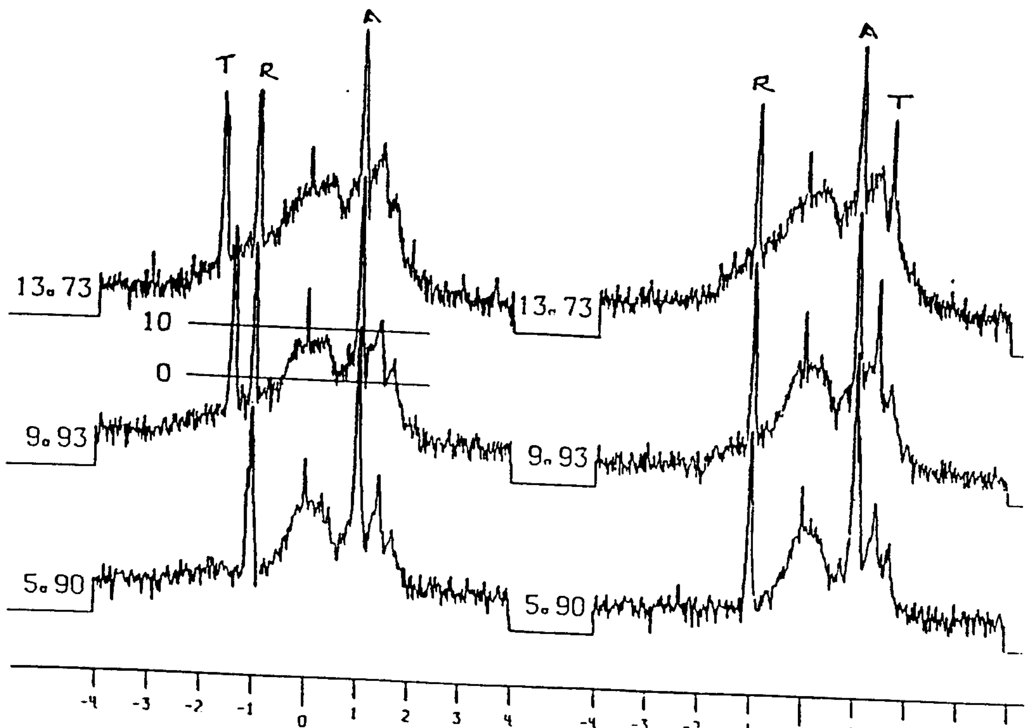


Figure 4. This is a data example made with a radar of less capability than that assumed for this report. An approximately 30 dBsm target T is shown approaching (right) and receding (left) in the presence of the sea echo. The format is of received power versus Doppler - normalized to the resonant wave frequency for three operating frequencies, 5.9, 9.93, and 13.73 MHz. The resonant wave or Bragg peaks are marked A for approaching and R for receding. The peak at zero Doppler is due to land in antenna side lobes. The 10 and 0 dBsm RCS levels are indicated by horizontal lines on the 9.93 spectrum; the noise level is at approximately -10 dBsm

Signal-to-Noise Ratio Versus Range - Probability of Detection: The radar range equation and loss curve for 10 MHz of Figure 2, an average transmitter power of 1 kW, an antenna gain product of 30 dBi, a noise level of -158 dBw/Hz, and a RCS of 0 dBsm are used to give SNR. A processing gain of 20 db is added for 100 sec. coherent integration time (CIT); this is a desirable and practical length processing time for surface targets. A probability of detection (Pd) greater than 90% is expected with a SNR of 20 dB. Values used in calculations are given in Table I.

Range nmi	PGtGrσ dB	$(4\pi/\lambda)(1/L_b)$ dB	-No dBw/Hz	CIT dBs	SNR dB
5	60	-163	158	20	75
10	60	-176	158	20	62
20	60	-191	158	20	47
40	60	-208	158	20	30
80	60	-231	158	20	7

Table I Values used for calculating SNR are tabulated.

Figure 5 provides a plot of SNR versus range. In addition to the curve made from the Table I, data that takes into account the added losses due to a Phillips Isotropic Wave Spectrum fully developed by a 30 knot wind is plotted (6). Typical shipping with RCS in the 30 to 50 dBsm sizes could be detected and tracked at ranges beyond 100 nmi. The example 0 dBsm target returns enough energy for detection and tracking out to 40 nmi but may be obscured by clutter depending upon its speed, the sea state and the spatial resolution cell size.

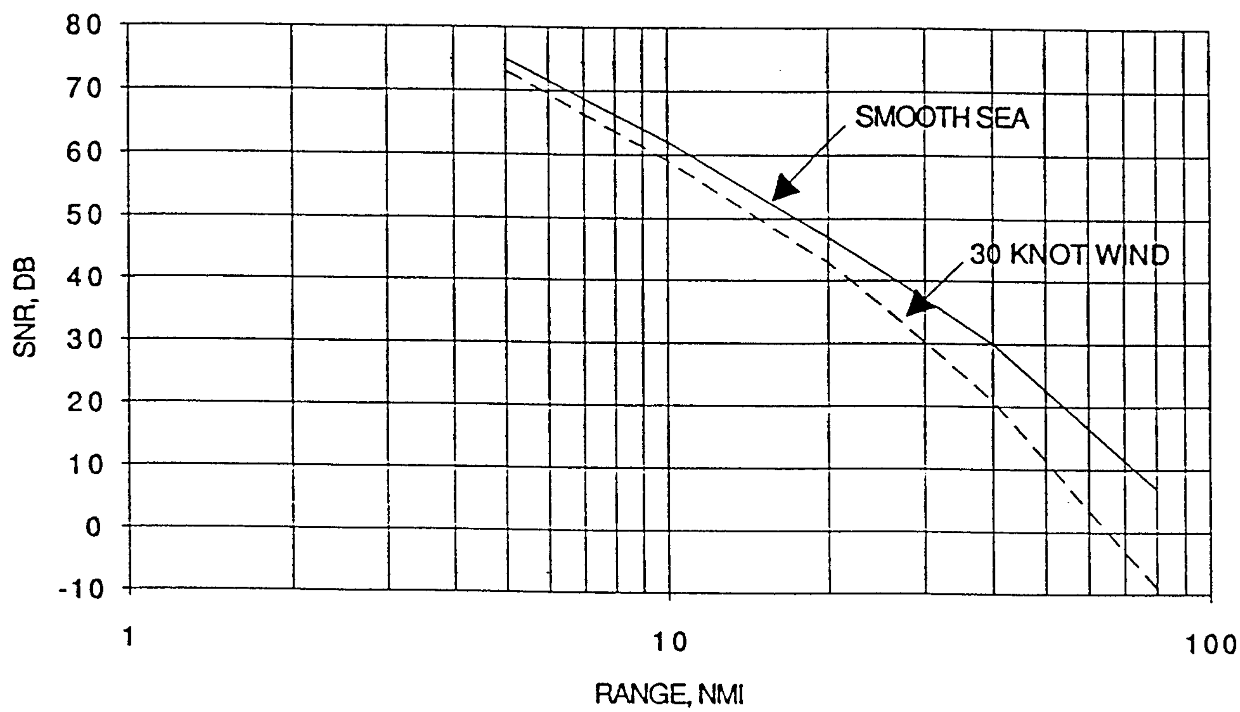


Figure 5 Signal-to-Noise ratio is plotted versus range from Table I by the solid curve. The dashed curve gives SNR when the path loss has been increased by a sea roughened by a 30 knot wind.

Discussion: HF Groundwave radar sited on the beach can monitor conventional coastal shipping out to ranges beyond 100 nmi from the radar. Small seaworthy surface craft that have some freeboard and are constructed with some electrically conductive material can be detected and tracked from 40 nmi into 5 nmi ranges with radar designs that are on the market. For very small and slow targets the sea clutter level will limit detection before noise does. The clutter limitation is a function of sea state, and the clutter obscuration can be reduced with higher spatial resolution.

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(5) Barrick, D. E., J. M. Headrick, R. W. Bogle, and D. D. Crombe "Sea Backscatter at HF: Interpretation and Utilization of the Echo" Proc. IEEE, vol. 62, June 1974.

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